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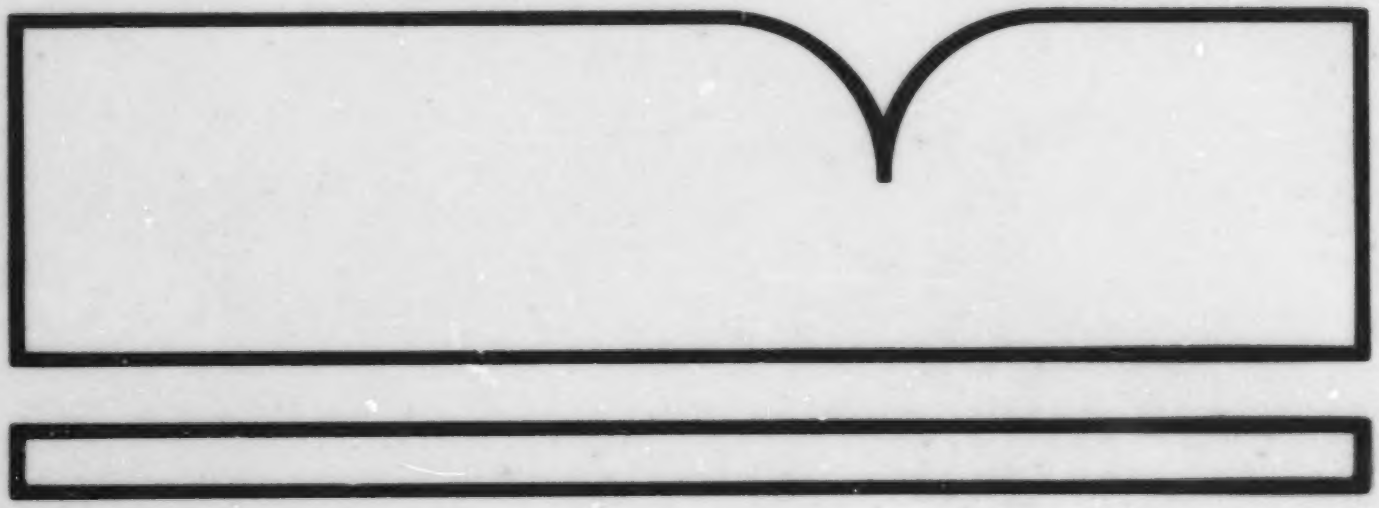

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16. ABSTRACT

Thermodynamics is the basic foundation of many engineering practices. Environmental engineering is no exception, it is using thermodynamic principles in many applications. In particular, those who are involved in the incineration of various wastes such as hazardous and municipal wastes, pesticides and sludges, and hospital and institutional wastes require a full understanding of basic thermodynamics in order to successfully conduct their jobs. The objective of this Paper is to present, and to illustrate the use of, some basic thermodynamic principles in order to assist engineers, managers, permit writers, the public, and any other interested parties in their evaluation of the incineration process.

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THERMODYNAMIC FUNDAMENTALS USED IN HAZARDOUS WASTE INCINERATION

by

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For Presentation at the 1990 Incineration Conference
to be held in San Diego, California on May 14-18, 1990

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ABSTRACT

Thermodynamics is the basic foundation of many engineering practices. Environmental engineering is no exception, it is using thermodynamic principles in many applications. In particular, those who are involved in the incineration of various wastes such as hazardous and municipal wastes, pesticides and sludges, and hospital and institutional wastes require a full understanding of basic thermodynamics in order to successfully conduct their jobs. The objective of this Paper is to present, and to illustrate the use of, some basic thermodynamic principles in order to assist engineers, managers, permit writers, the public, and other interested parties in their evaluation of the incineration process.

INTRODUCTION

The incineration of hazardous and toxic waste is an environmental issue of the 1990s and may continue as long as industry produces waste. The exact amounts of hazardous wastes produced in the United States are difficult to predict. However, in 1984, EPA estimated that over 264 million metric tons of organic/toxic wastes were generated (1). Previous improper disposal of industrial waste has resulted in a serious threat to human health and the environment. In responding to this critical problem, Congress enacted a series of laws with unprecedented scopes and impacts on waste disposal and dump site clean-up activities. These laws, and some of their chief thrusts, were:

1. RESOURCE CONSERVATION AND RECOVERY ACT OF 1976 (RCRA)
   (Public Law 94-580)
   - Set safety standard regulations for handling hazardous wastes.
   - Required permits for the operation of hazardous waste storage, treatment, and disposal facilities.

2. HAZARDOUS AND SOLID WASTE AMENDMENTS OF 1984 (HSWA)
(Public Law 98-616)

- Established a time-table for restricting untreated hazardous waste from land disposal.

3. TOXIC SUBSTANCES CONTROL ACT OF 1976 (TSCA)
(Public Law 94-469)

- Banned manufacture and use of polychlorinated biphenyls (PCBs).

4. COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY ACT (CERCLA) [COMMONLY KNOWN AS THE SUPERFUND ACT OF 1980]

- Created a $1.6 billion Trust Fund for dump site clean-up.
- Imposed liability for those who release hazardous substances into the environment.

5. SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 (SARA) (Public Law 99-499)

- Not only reauthorized the Superfund Program but greatly expanded the provisions and funding of the initial Act.

The full impact of these various statutes is hard to judge. They will, at least, result in a drastic modification of current waste management practices. For example:

- By 1990, untreated hazardous waste will be banned from further land disposal.

- The more traditional and lowest cost methods of direct landfilling, storage in surface impoundments and deep-well injection will either be banned or controlled by very restrictive regulations. Waste generators and other segments of the waste management industry will be searching for effective alternative technologies such as incineration, waste minimization, waste reuse, physical/chemical/biological treatments, and chemical stabilization/solidification of residues.

EPA's research data and industry's operating experience indicate that incineration, when compared to the other alternative technologies, has the

highest overall degree of destruction and control for the broadest range of waste streams (2). The waste streams may include municipal waste, hazardous waste, toxic substances (PCB), hospital waste, spent pesticides, sludges from both municipal and industrial wastewater treatment processes, and other unclassified waste such as military waste. In addition, incineration would offer the following advantages:

- Once a waste is incinerated, it will not resurface again.
- The volume and weight of a waste can be reduced to a fraction of its original size.
- For those high-heat content wastes, energy can be recovered for other applications.
- Incineration only takes a few seconds to destroy what may take years to decompose in landfills.

As a result, it is believed that implementation of the HSWA land disposal restriction regulations and the waste generator's concern over long-term liability will increase the utilization of incineration. It is expected that in the future, more incinerator manufacturers, researchers, regulatory personnel and the representatives of the public will see increased involvement with the incineration option and will be looking for more incineration information for guidance.

Incineration of various wastes requires the compliance with both State and Federal regulations under various statutes. For hazardous waste incineration, the operation of a hazardous waste incinerator must meet the requirements of RCRA which are summarized in Table 1.

TABLE 1.

Summary of RCRA Incineration Standards

1. An incinerator must achieve a destruction and removal efficiency (DRE) of 99.99 percent for each principal organic hazardous constituent (POHC) designated for each waste feed. Initially, EPA suggested the use of compound incinerability and concentration for selecting POHCs. It further suggested that heat of combustion (ΔHc) be used as the measure of compound incinerability in its preliminary guidance (2,16).

2. DRE for an incinerator/air pollution control system is defined by the following formula:

$$DRE\ (\%) = 100\ (Win - Wout)/Win$$

where DRE = destruction and removal efficiency, percent

Win = mass feed rate of POHC to the incinerator

Wout = mass emission rate of POHC to the atmosphere (as measured in the stack just prior to discharge)

3. An incinerator burning hazardous waste containing more than 0.5 percent chlorine must remove 99 percent of the hydrogen chloride from the exhaust gas.

4. An incinerator burning hazardous waste must not emit particulate matter exceeding 180 mg/dscm corrected to 7 percent O_2 in the stack gas.

5. A trial burn (or data equivalent to a trial burn) is generally required to demonstrate the ability of a hazardous waste incinerator to comply with the above performance levels.

Thermodynamics is the fundamental basis of many engineering fields. The design and operation of an incinerator must be based on the principles of thermodynamics. The purpose of this Paper is to provide information on how thermodynamics is applied to the waste incineration process. This Paper reviews thermodynamic fundamentals (3,4,5,6) and current waste incineration activities (7,8,9,10,11,12,13,14,15 and 16). Specifically, it covers enthalpy, the First Law of Thermodynamics, chemical kinetics, etc. This Paper also compiles a list of terms which should be useful to those who need a ready reference for certain incineration definitions.

SOME THERMODYNAMICS BASICS

Thermodynamics is a science encompassing all forms of energy transformation; it includes heat and work. It covers mainly the chemical and the physical properties of substances that are involved in the energy transformation. The fundamental basis for thermodynamics results from numerous experimental observations which have been formalized into certain basic laws known as the Zero, First, Second and Third Laws of Thermodynamics. For application to hazardous waste incineration, the First Law is mostly used.

A thermodynamic process is a change of a system from one state to another. The path of a process is the series of the states through which the system passes during the process. For example, heat and work are path functions. A path function can be expressed as:

$$x_{1-2} = \int_1^2 dx$$

A thermodynamic property is a characteristic of a system which is observable while the system is in any one condition or state. Examples of the thermodynamic properties include temperature, pressure, volume and density. Mathematically, a thermodynamic property is a point function which can be expressed by a function such as:

$$x = f(y,z)$$

The x value is called a point function, because at each point on a plane of y and z coordinates, there is a discrete value of x. In other words, the above equation indicates that any one thermodynamic property can be a function of any two other properties.

Some thermodynamic properties can also be shown on property diagrams. For example, Figure 1 is a P-v (pressure-specific volume) diagram and Figure 2 is a T-v (temperature-specific volume) diagram. Steam properties are probably the most widely used set of thermodynamic properties applied to engineering applications. Table 2 contains some steam properties and is commonly referred to as "The Steam Tables".

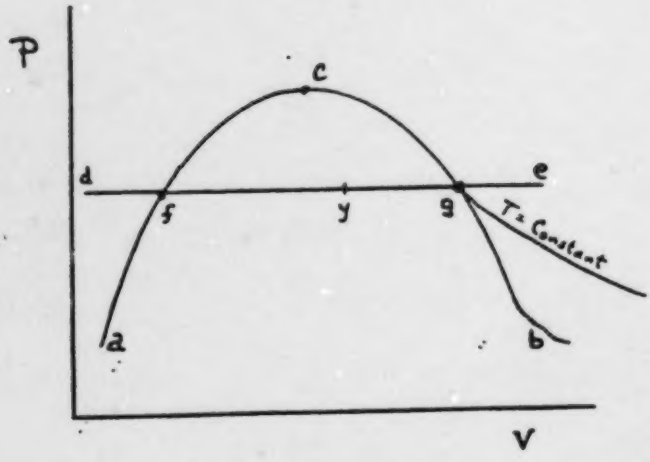

Figure 1. P-v diagram

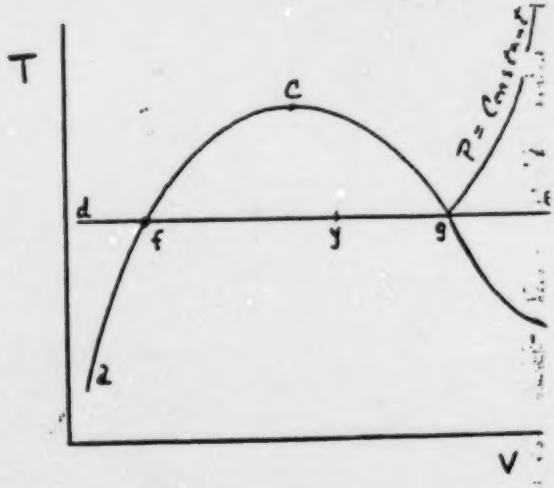

Figure 2. T-v diagram

In Figure 1 for example:

- afcgb is the saturated curve
- afc is the saturated liquid curve
- cgb is the saturated vapor curve
- df is the liquid zone
- ge is the vapor zone
- fg is the liquid-vapor mixture zone
- c is the critical point

The properties at point y are:

- Specific volume = $v_y = v_f + x\ (v_g - v_f)$
- Internal energy = $u_y = u_f + x\ (u_g - u_f)$
- Enthalpy = $h_y = h_f + x\ (h_g - h_f)$

where, quality x = vapor mass/(liquid mass + vapor mass)

The values of v and h along the saturated liquid and vapor curve in Figure 1 can be obtained from Table 2.

NOTE: This paper has 59 pages which is too long for the proceedings. For those who are interested in the full paper, please contact
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